

# Inspection of GEO Spacecraft for Commercial and Military Customers

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Tactical Technology Office

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NASA Johnson Space Center

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## Phoenix program vision

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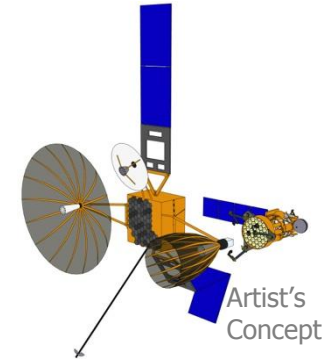
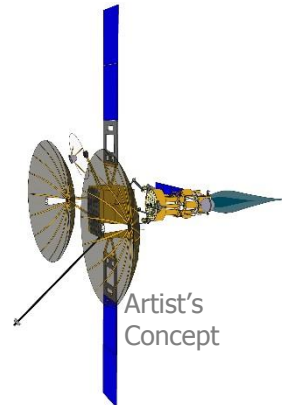
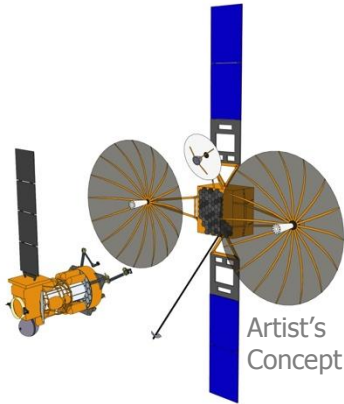
“Communications satellites in geosynchronous orbit, approximately 36,000 kilometers above the Earth, provide vital communication capabilities to Warfighters and others. Today, when a satellite fails, we usually face the expensive prospect of having to launch a brand new replacement. Our Phoenix program strives to develop and demonstrate technology to robotically service, maintain, and construct satellites in the harsh environment of geosynchronous orbit.”

– DARPA Director Arati Prabhakar, March 2014

**The DARPA GEO robotic servicing program seeks to revolutionize space reliability, capability and operations**



# Mission ensemble for a DARPA GEO robotic multi-mission vehicle



- Provide unparalleled **high-resolution images on request** of spacecraft experiencing anomalies
- Inspections would be enabled by a RMMV with a sensor suite and dexterous arms with cameras
  - Stand-off inspections (50m-1km)
  - Close inspections (5m-50m)
  - Docked inspections
- **Cooperatively move spacecraft in orbit**, recover spacecraft in off-nominal orbits and extend lifetimes through propellant conservation
  - N/S station keeping recovery
  - End-of-Life to GEO graveyard
  - Repositioning within the GEO belt
- **Assist spacecraft experiencing anomalies**, helping to ensure that missions can be completed at maximum performance
  - Free stuck appendages
  - Supplement attitude control
  - Perform docked inspections



## RMMV notional system configuration

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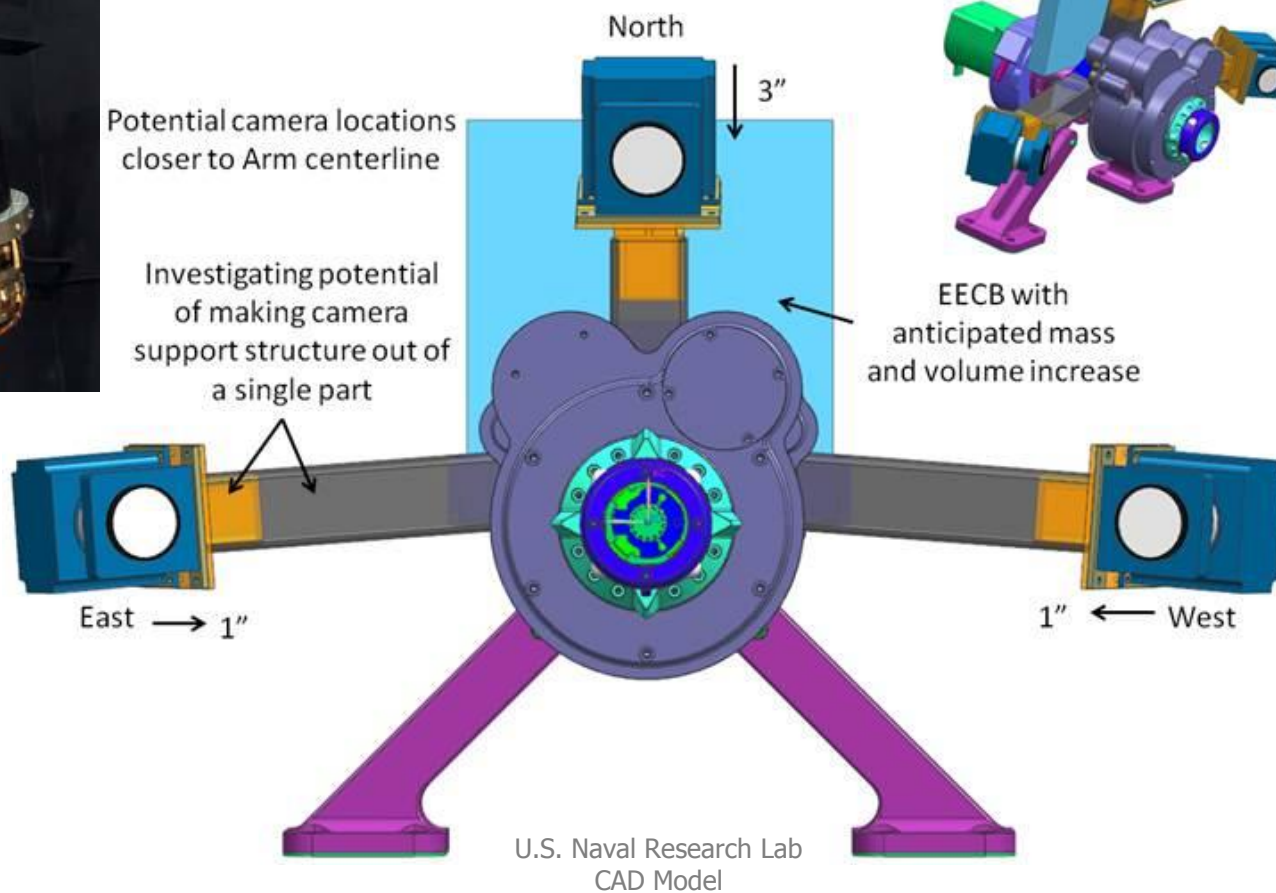
- Long-life bus and robotic components (5-15yr)
  - Probably electric propulsion for high  $\Delta V$  capability
- Two high-strength robotic arms (FRIEND)
  - Capability for cooperative maneuver of large satellites
  - Strength to accommodate forces from small motions
  - End cameras primarily for control during docking
  - Excellent imaging capability
- Longer, lighter secondary arm for cameras/lights
- Redundant RPO sensor suite
- Propulsion, attitude control, etc., suitable for RPOD
- Ground segment to include very high fidelity simulator
  - Operations training, mission validation, customer interactions



# Primary robotic arm: DARPA FREND



U. S. Naval Research Lab





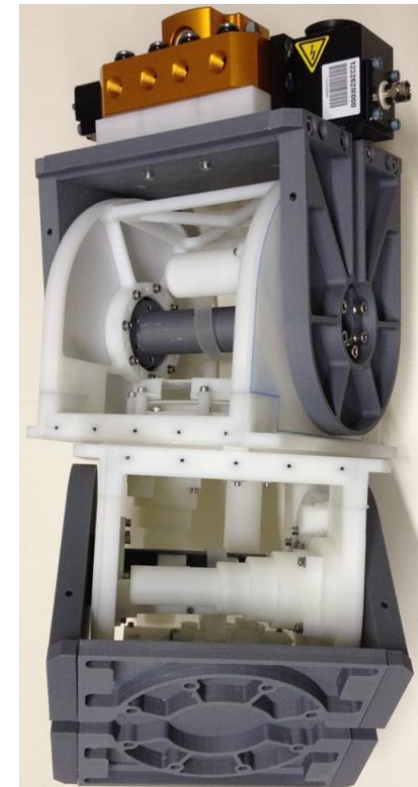
Secondary arm: possibly longer, more degrees of freedom

Considering modular and reconfigurable concepts

Example: MDA-US Systems  
"MeDUSA Mk III" concept  
--Up to 4m overall length

© MDA

3 degree-of-freedom  
joint modules

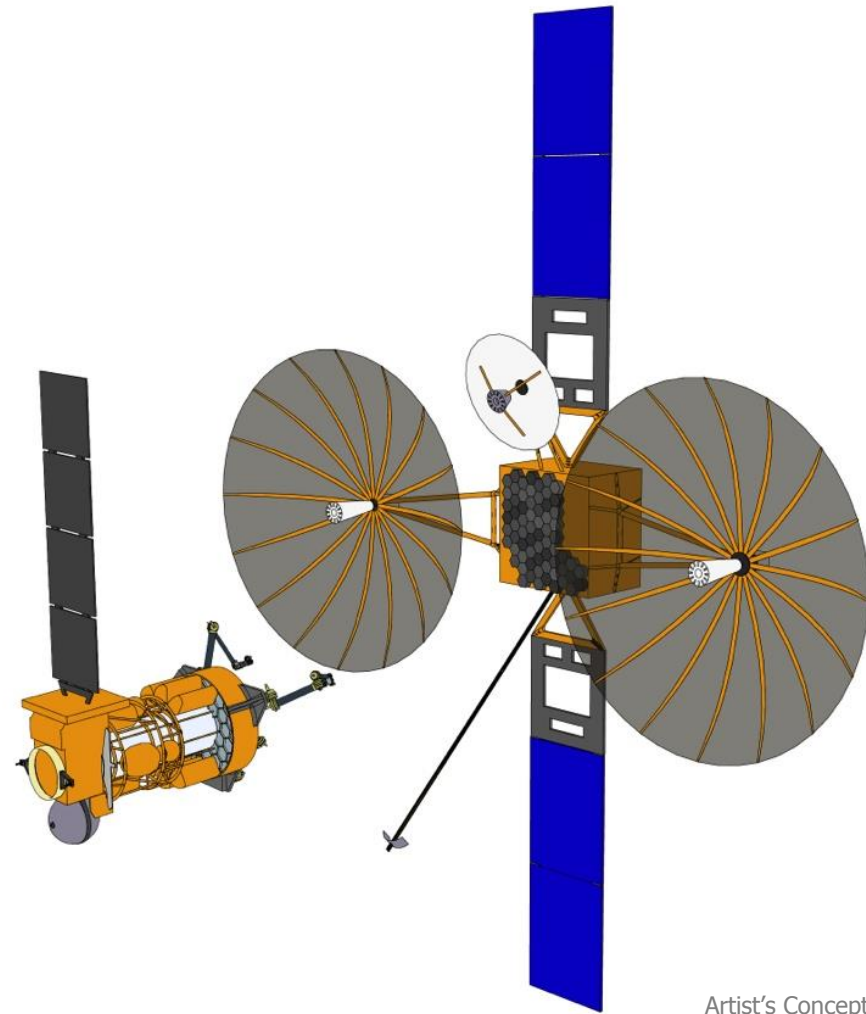


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## Goal: High-resolution cooperative inspection

- Requirement: unparalleled high-resolution multi-sensor images of spacecraft experiencing anomalies
- Multi-DOF arms will permit imaging of difficult-to-see sites
- Potential benefits:
  - Identify and possibly resolve failures
  - Enable forensics and failure root cause determination
  - Attribute failures to natural environment, engineering or other causes



Artist's Concept



## GEO inspection enhances security

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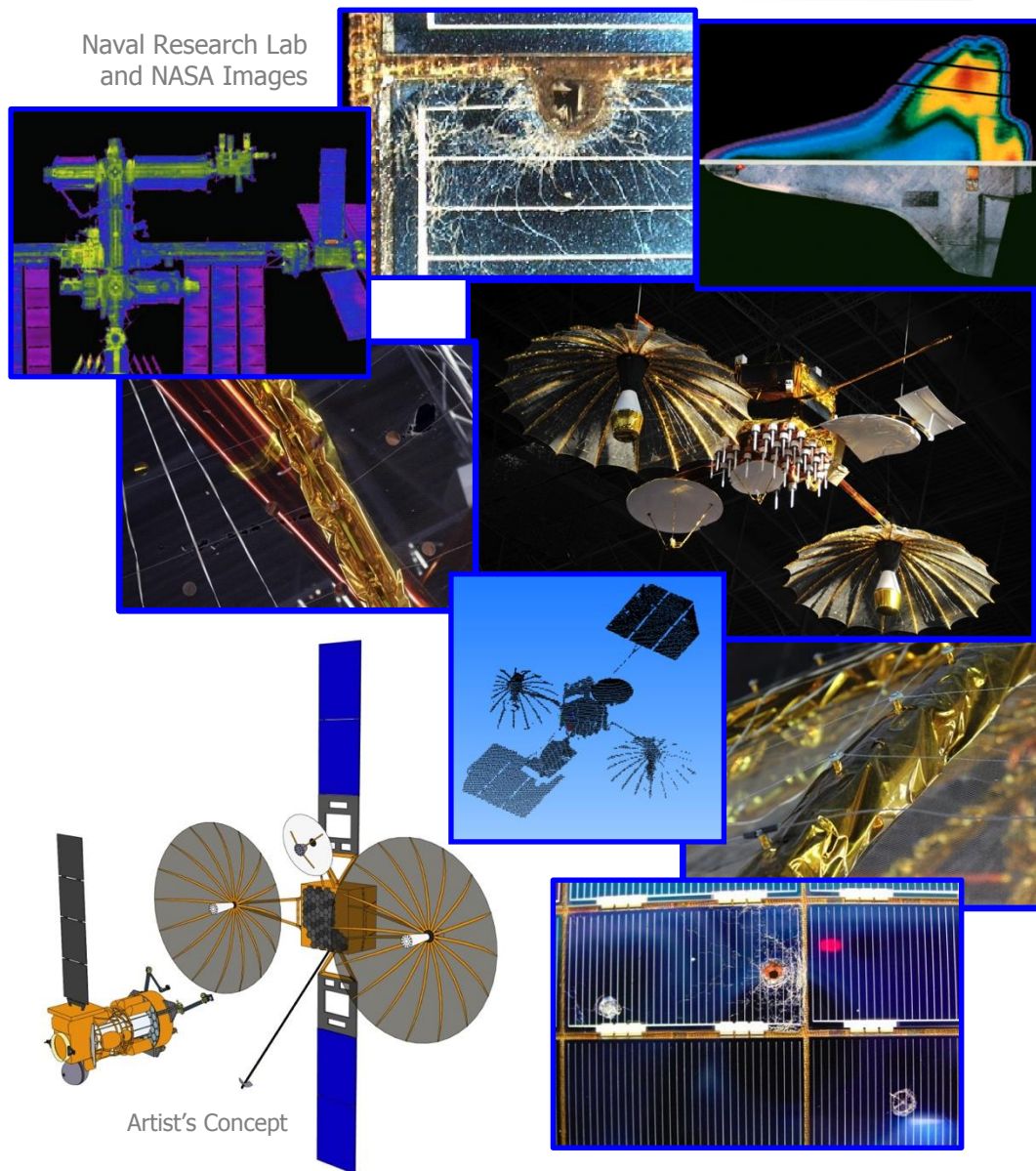
- Vital US military capabilities in GEO include:
  - Nuclear-survivable communications (Advanced EHF)
  - Missile launch detection/warning (SBIRS)
- Spacecraft can fail because of design flaws, natural phenomena, or other causes
- Resolving which of these caused a loss of a critical national capability is of paramount importance
- Robotics provide the means for ***exquisitely close cooperative inspection*** and high resolution imaging—including of difficult-to-access locations on the exterior
- “CSI In Space”
- Increase transparency, reduce uncertainty & potential misperception



# GEO inspection unique attributes

- Would be done in context of robotic servicing
- Combine RPO sensor suite and dexterous arms with cameras
  - Stand-off inspections (50m-1km)
  - Close inspections (5m-50m)
  - Docked inspections, including obscured locations
- Could be performed while docked or drifting
- Arm dexterity provides ***absolutely unique access***, and reduces propellant expenditure

Naval Research Lab  
and NASA Images



Artist's Concept



## GEO inspection as a commercial resource

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- More than 300 spacecraft in GEO provide TV, mobile telephony, data transfer—a \$110B market
- Among the causes limiting satellite performance:
  - Solar panel deployment anomaly (complete or partial)
  - Antenna deployment anomaly (complete or partial)
  - Propulsion anomalies
- Insurance claims cover portion of satellite costs but not lost revenue
- Inspection would be the *first step in making decisions* about attempts to correct anomalies
- Could enable future designs to be less exquisite/redundant



# Commercial satellite anomalies 2010-2011

Feb. '10 - IS-4: satellite control processor (SCP) failure. Deemed "unrecoverable".<sup>1</sup>



Q3 2011: DirecTV 10 experiences propulsion system problem.



May 2010: Russian Satellite Communications Co.'s Express-AM1 satellite loses attitude control.



May '11 – Telstar 14R: North solar array fails to deploy.



April 2010

Mar. '10 - AMC-16: partial power loss due to a solar array anomaly. Result is "reduced capacity".



Apr. '10 - Galaxy-15: loses control, drifting through the GEO belt and posing a significant interference threat.



Jul. '10 - Insat-4B: loses half its broadcast capability due to a solar array failure.



May '11 – Intelsat New Dawn: failed C-band antenna deployment.



2011 - AMC-15: partial power loss due to a solar array anomaly.



Feb 2011

June 2011

Dec 2011

Images from Gunter's Space Page



# Commercial satellite anomalies 2012-2013

Jan. '16 – AMC 16:  
further solar array  
circuit failure.



Sep. '12, Nov. '12, Jul.  
'13 – Echostar XII:  
Further solar array  
anomalies.



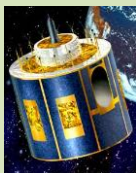
Sep. '12 – GOES 13:  
increased sensor noise;  
put into standby mode.



Dec. '12 – Yamal 402:  
3<sup>rd</sup> stage failure;  
onboard propellant used  
for final maneuvering



May '12 – Meteosat  
8: Sun sensor issues.



Jun. '12 – IS-19:  
South solar array  
failed to deploy.



Q2 '12 – Echostar VI:  
Reduced solar array  
power



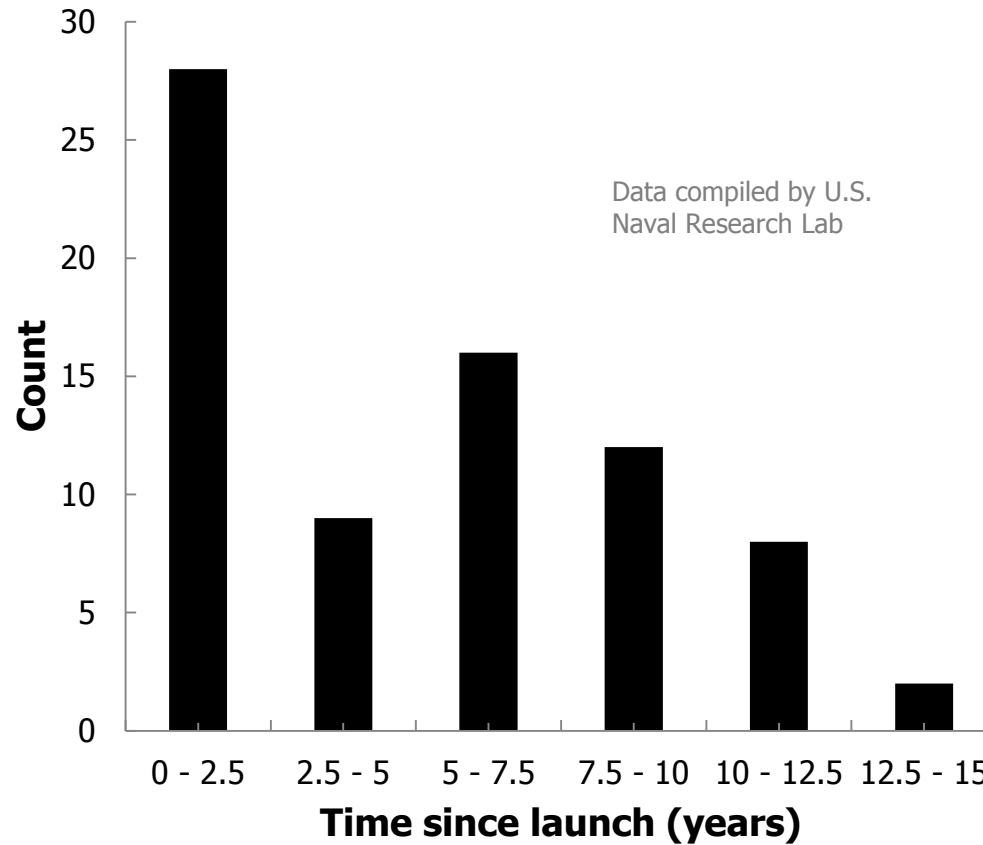
Apr. '14 – Amazonas 4A:  
Unspecified power  
subsystem anomaly.



Images from Gunter's Space Page

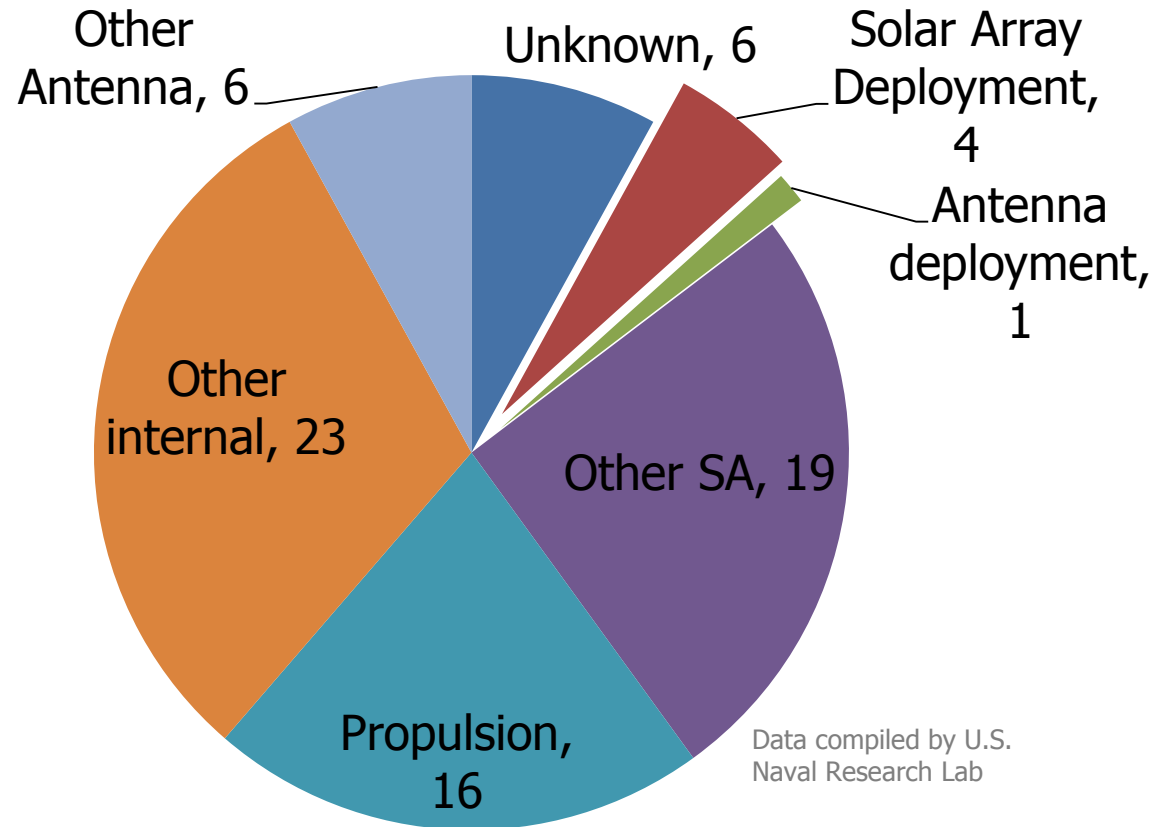


# Age of commercial spacecraft at anomaly





## Breakdown of anomalies by type

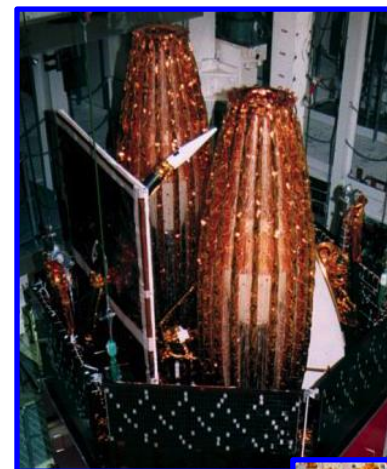


Some of these will be addressable using the GEO servicer capabilities

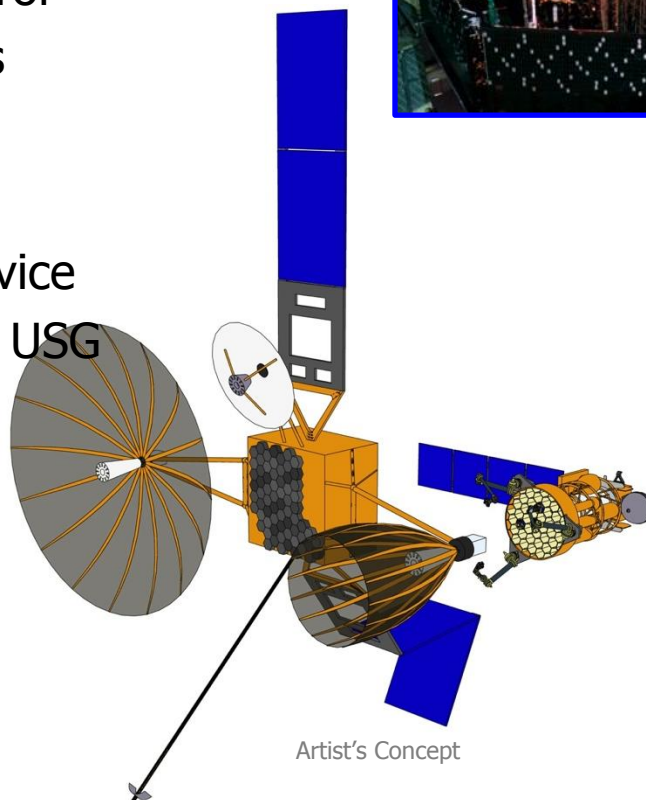
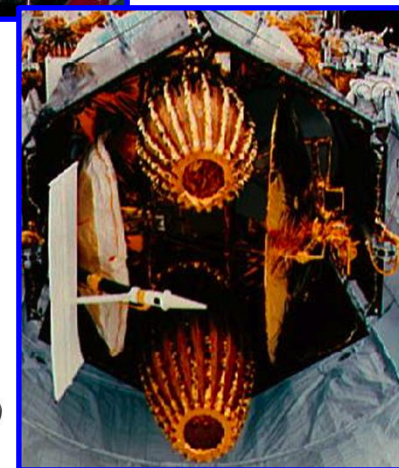


## Goal: Anomaly resolution

- A GEO robotic multi-mission vehicle would assist spacecraft experiencing anomalies, helping ensure mission completion
  - Free stuck appendages
  - Supplemental attitude control
  - Perform docked inspections
- Potential benefits:
  - Increased fleet resilience
  - Episodic but high-value service
  - Of particular importance to USG self-insured spacecraft



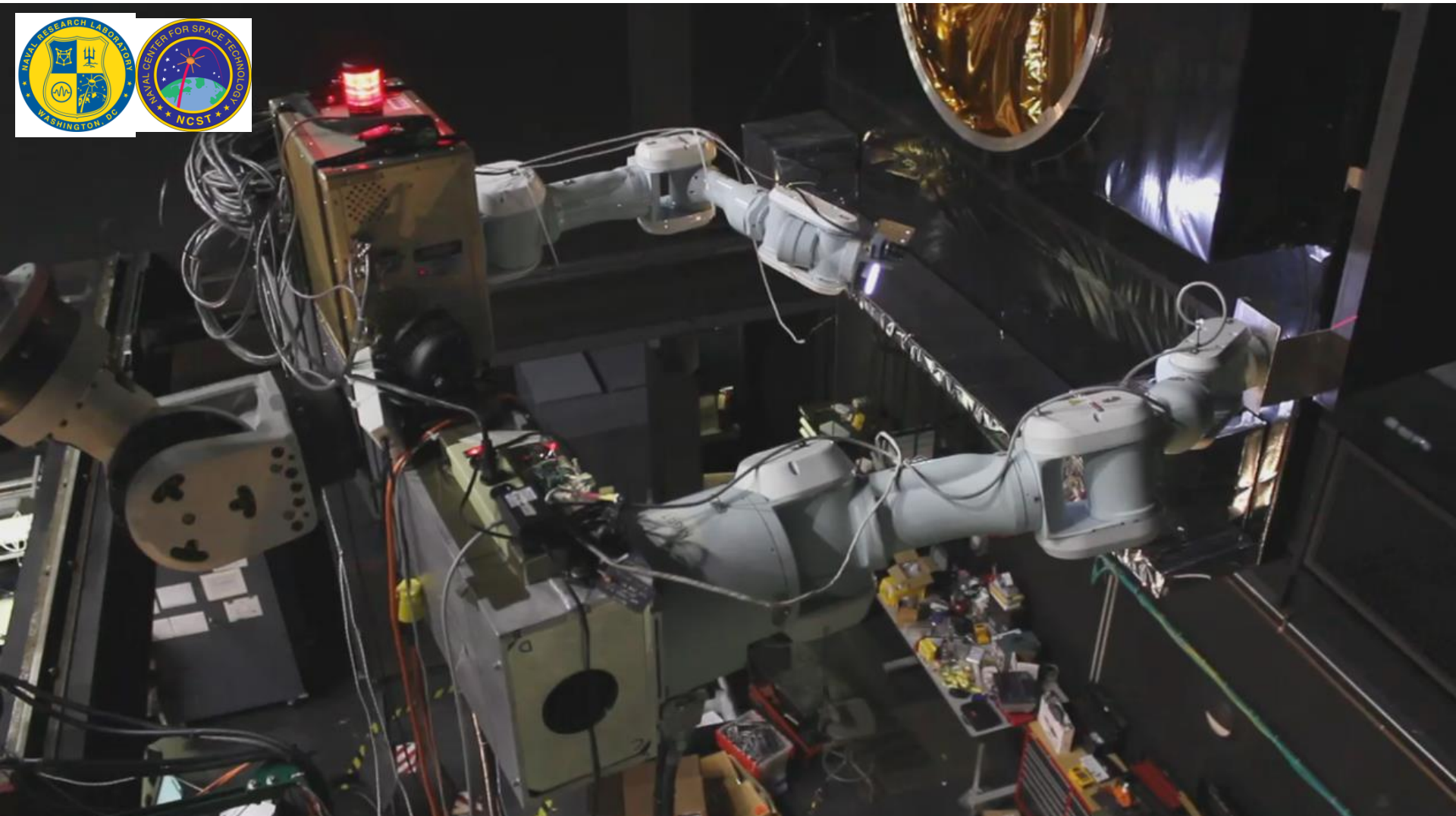
NASA Images



Artist's Concept



# Early lab test: Freeing a solar panel

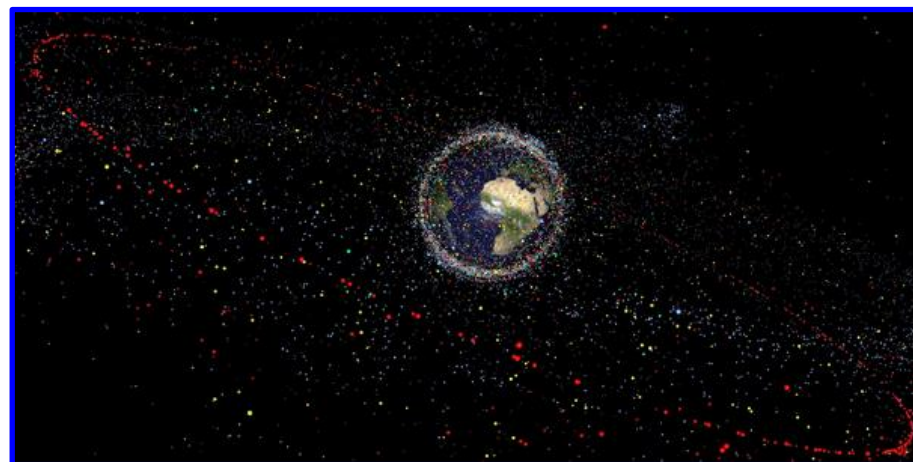
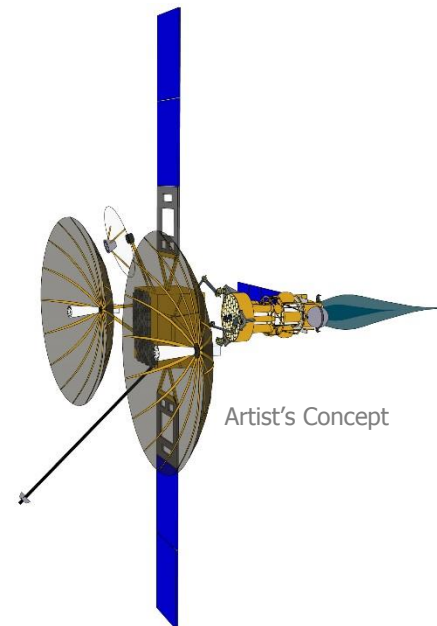


U.S. Naval Research Lab



## Goal: Orbit modification assistance

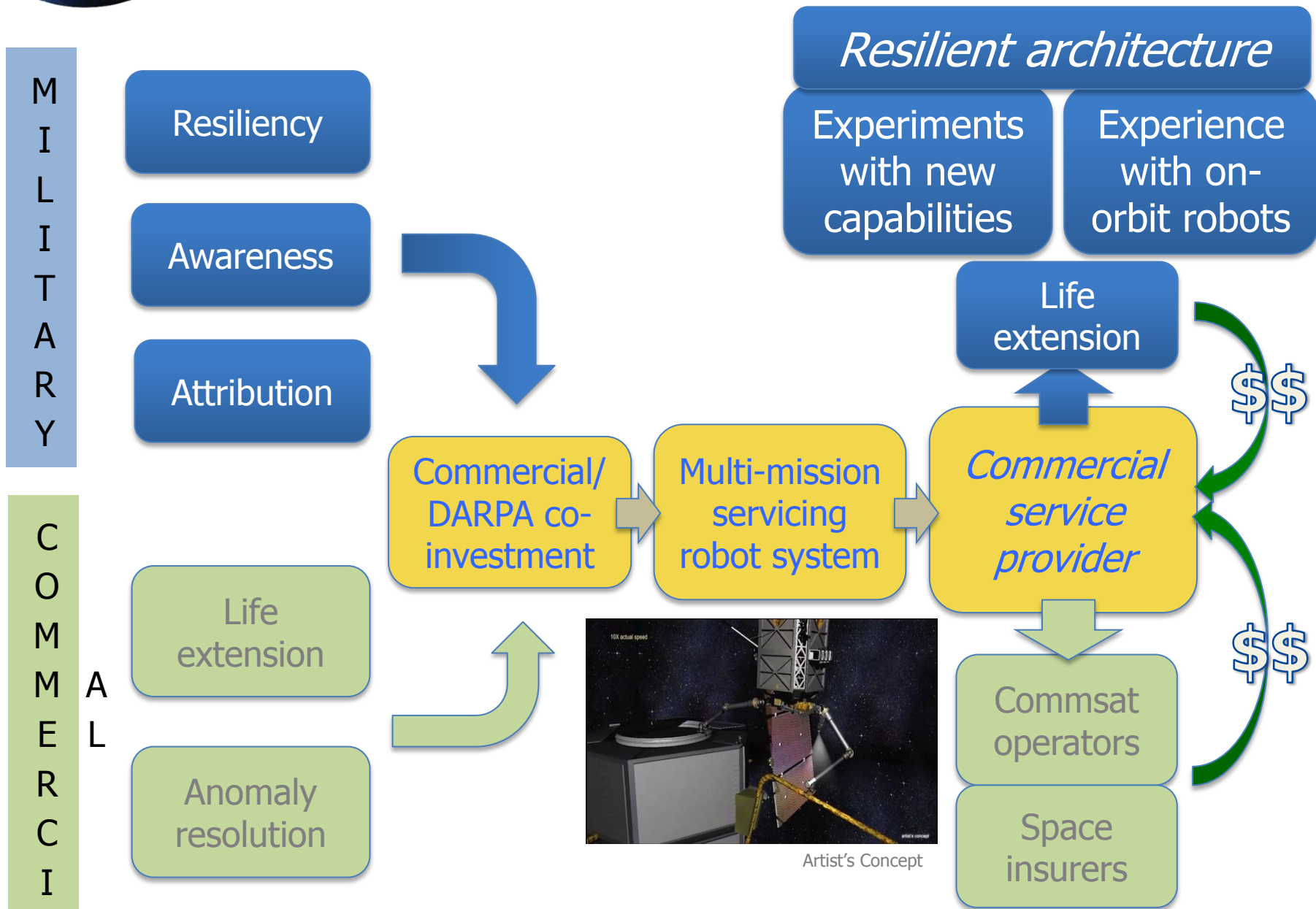
- A GEO robotic multi-mission vehicle would provide assistance to move spacecraft in orbit, recover spacecraft in off-nominal orbits and manage space traffic
  - N/S station keeping recovery
  - End-of-Life to GEO graveyard
  - Repositioning within the GEO belt—manage slots
  - Propulsion anomalies
- Potential benefits:
  - Economic benefits of deferred disposal and correction of propulsion anomalies
  - Can assist with recovery from avoidance maneuvers
  - Future capability: repositioning of navigation hazards



[www.spaceflightnow.com](http://www.spaceflightnow.com)



# A potential business model for two customers





## Change is coming

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- If this demonstration is successful, we expect builders of future spacecraft to take advantage of new capabilities:
  - Less propellant, more payload
  - Robotic assistance with large aperture deployment
  - Reduced redundancy
  - Build for servicing
  - Etc., etc.
- New space architectures :
  - Large structure assembly
  - Large aperture assembly
  - Modular spacecraft design concepts
- Government could contract for some time to conduct on-orbit robotics experiments



## Conclusions

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- The DARPA robotic GEO servicer program seeks to provide new capabilities for robustness and productivity of GEO satellite fleets
- Inspection would be an inherent capability of the robotic systems and RPO sensor suites that would be employed
- GEO inspection has both potential commercial and national value
- We are exploring innovative ways to enable the capability



[www.darpa.mil](http://www.darpa.mil)